HIGH TEMPERATURE ELECTRONICS, COMMUNICATIONS, AND SUPPORTING TECHNOLOGIES FOR VENUS MISSIONS

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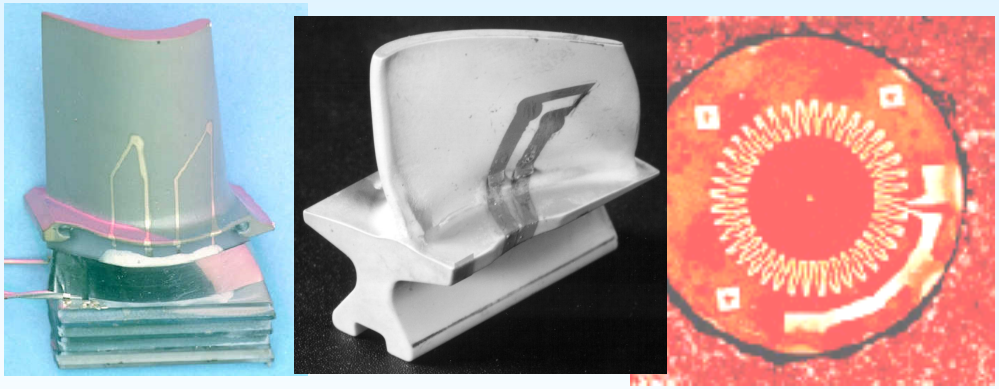
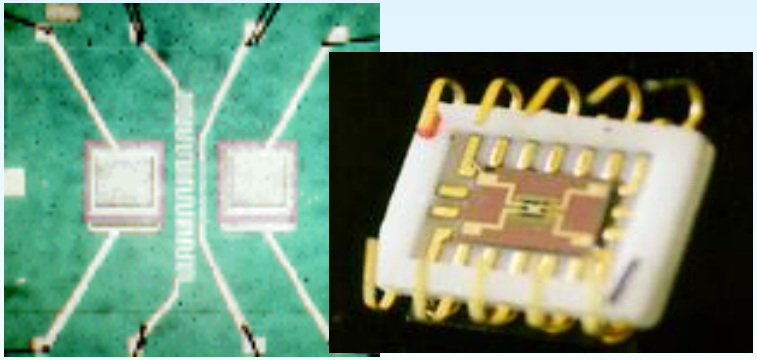
SENSORS AND ELECTRONICS TECHNOLOGY BRANCH

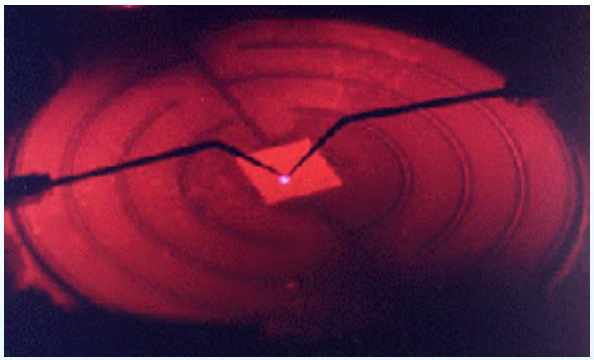
SCOPE OF WORK



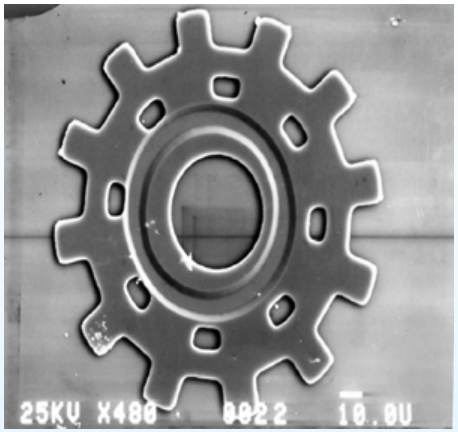
PHYSICAL SENSORS (T, Strain, Heat Flux)



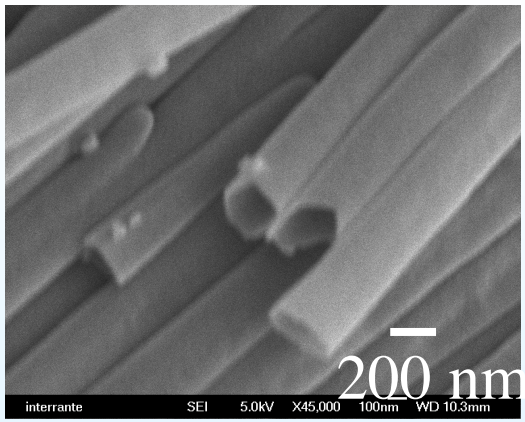
CHEMICAL SENSORS



SILICON CARBIDE HIGH TEMP ELECTRONICS



MICRO-ELECTRO-MECHANICAL SYSTEMS

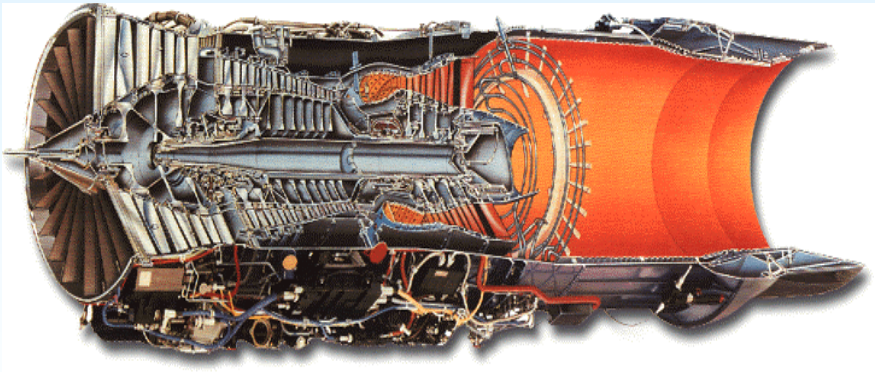


NANOTECHNOLOGY

NASA GRC: CUTTING EDGE DEVELOPMENT HARSH ENVIRONMENT SENSORS AND ELECTRONICS

HIGH TEMPERATURE ELECTRONICS AND SENSORS BENEFITS TO NASA MISSIONS

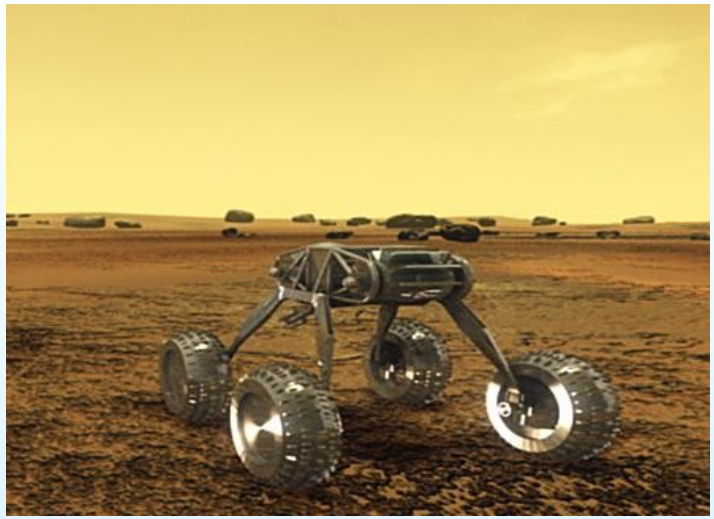
Intelligent Propulsion Systems



Space Exploration Vision PMAD

More Electric + Distributed Control Aircraft

Venus Exploration

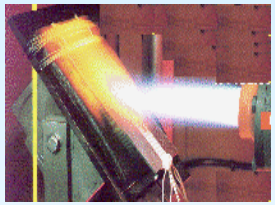


HARSH ENVIRONMENT VENUS MISSION REQUIREMENTS

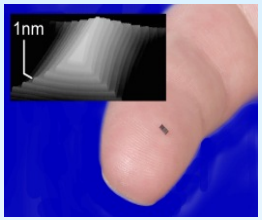
- SURFACE CONDITIONS
  - TEMPERATURE: 450-500 C
  - PRESSURE: 90 bar PREDOMINATELY (~100 TIMES EARTH)
  - SULFURIC ACID PARTICLES IN CLOUD DECK
  - 96.5% CO_2 and 3.5% N_2; Trace Gases include H_2O, SO_2, CO, HCL, H_2, and HF
- SOME PARAMETERS OF INTEREST: TEMPERATURE, PRESSURE, CHEMICAL SPECIES, FLOW (WIND)
- TEMPERATURE CONTROL INCREASES SYSTEM COMPLEXITY/RISK TO MISSION
- NEED TO SHIELD SYSTEM FROM EXTREME ENVIRONMENTS YIELDS INCREASE IN SIZE AND WEIGHT
- LIMITED INFORMATION AVAILABLE FROM IN-SITU SYSTEMS DUE TO HARSH ENVIRONMENTS INVOLVED
- SCIENTIFIC COMMUNITY: LACK OF VIABLE HARSH SENSOR SYSTEMS SENSORS AND ELECTRONICS FOR IN-SITU CHARACTERIZATION
- IN SOME AREAS, NASA GRC HAS ALREADY TECHNOLOGY SOLUTIONS ISSUES NEEDED BY SMD FOR HARSH ENVIRONMENT APPLICATIONS

HARSH ENVIRONMENT ELECTRONICS AND SENSORS APPLICATIONS

- **NEEDS:**
  - **OPERATION IN HARSH ENVIRONMENTS**
  - **RANGE OF PHYSICAL AND CHEMICAL MEASUREMENTS**
  - **INCREASE DURABILITY, DECREASE THERMAL SHIELDING, IMPROVE IN-SITU OPERATION**

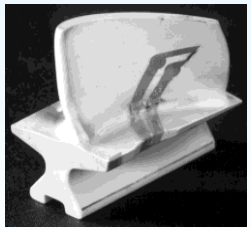


1998 R&D 100 Award



2004 R&D 100 Award

- **RESPONSE: UNIQUE RANGE OF HARSH ENVIRONMENT TECHNOLOGY AND CAPABILITIES**
  - **STANDARD 500C OPERATION BY MULTIPLE SYSTEMS**
  - **TEMPERATURE, PRESSURE, CHEMICAL SPECIES, WIND AVAILABLE**
  - **HIGH TEMPERATURE ELECTRONICS TO MAKE SMART SYSTEMS**

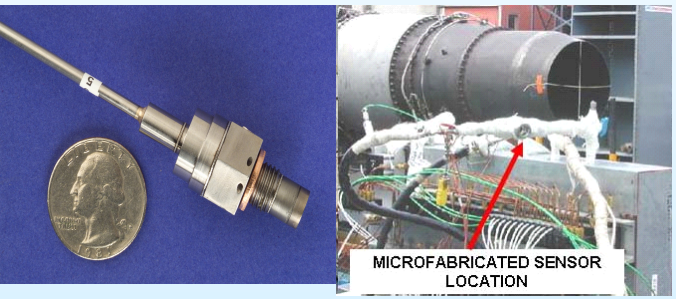


1995 R&D 100 Award

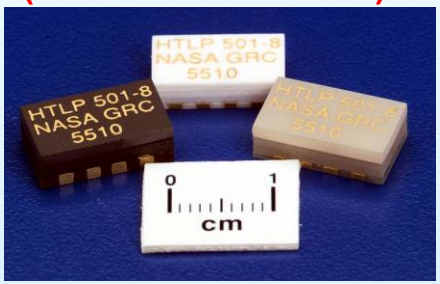
1991 R&D 100 Award

- **ALL-IN-ONE SHOP FOR HARSH ENVIRONMENT SYSTEM APPLICATIONS**
- **ENABLE EXPANDED MISSION PARAMETERS/IN-SITU MEASUREMENTS**

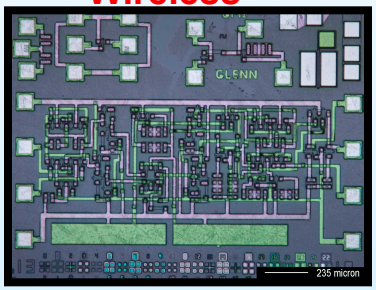
Range of Physical and Chemical Sensors for Harsh Environments



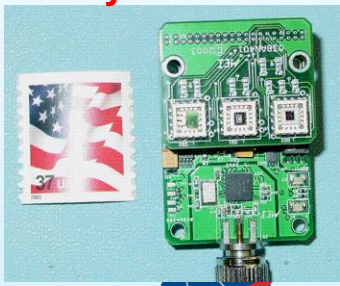
Harsh Environment Packaging (2000 hours at 500C)



High Temperature Signal Processing and Wireless

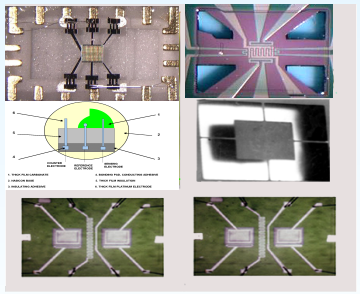


Long Term: High Temperature "Lick and Stick" Systems

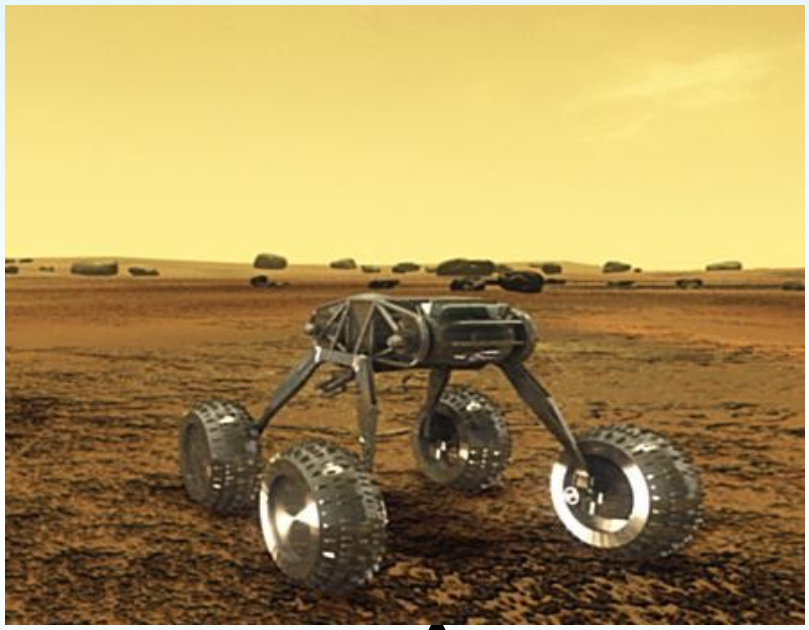


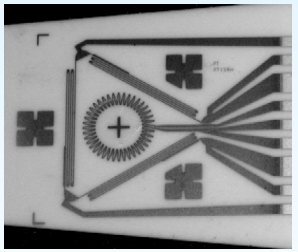
VENUS SCIENTIFIC MISSIONS LIMITED BY AVAILABILITY OF HARSH ENVIRONMENT SENSORS AND ELECTRONICS

NASA GRC HAS VAST RANGE OF HIGH TEMPERATURE EXPERIENCE AND IS IN A POSITION TO PROVIDE NEEDED SOLUTIONS

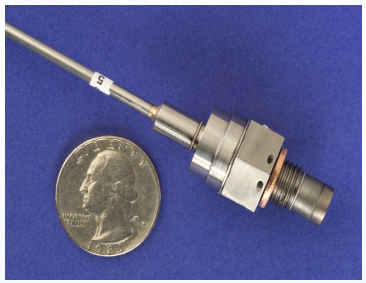


HIGH TEMPERATURE ELECTRONIC NOSE

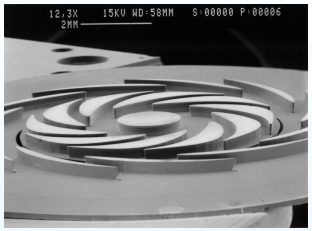




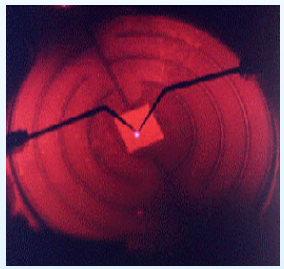
MULTIFUNCTIONAL PHYSICAL SENSOR ARRAY



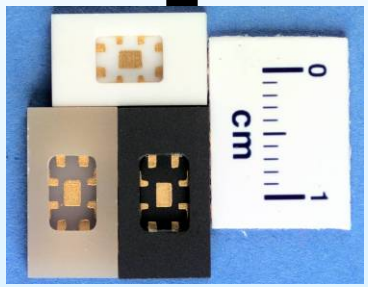
600°C PRESSURE SENSOR



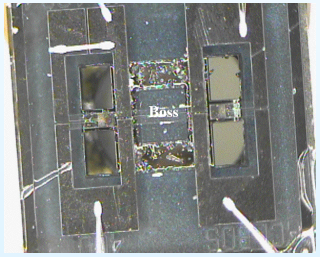
MICROENGINE, ACTUATORS, AND FUEL DELIVERY



HIGH TEMPERATURE MICROELECTRONICS



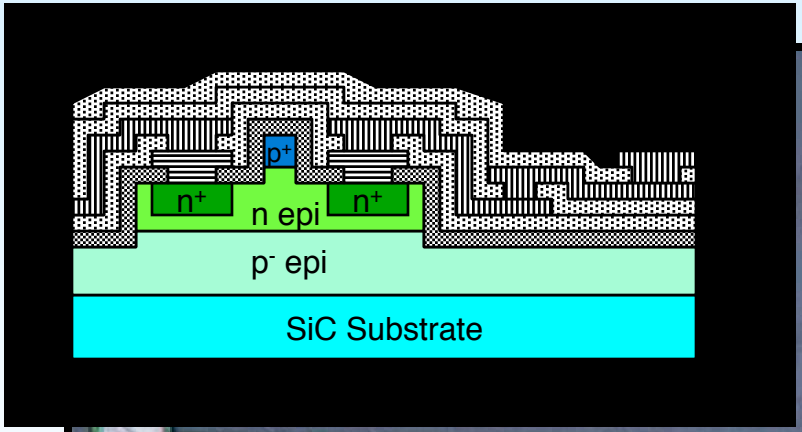
HIGH TEMP PACKAGING



Hi-g SiC ACCELEROMETER

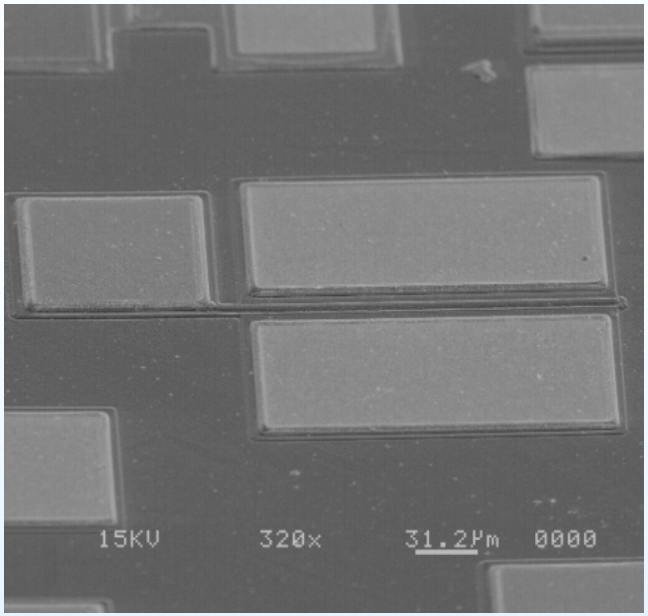
NASA/GMI 6H-SiC JFET Amplifier Circuit

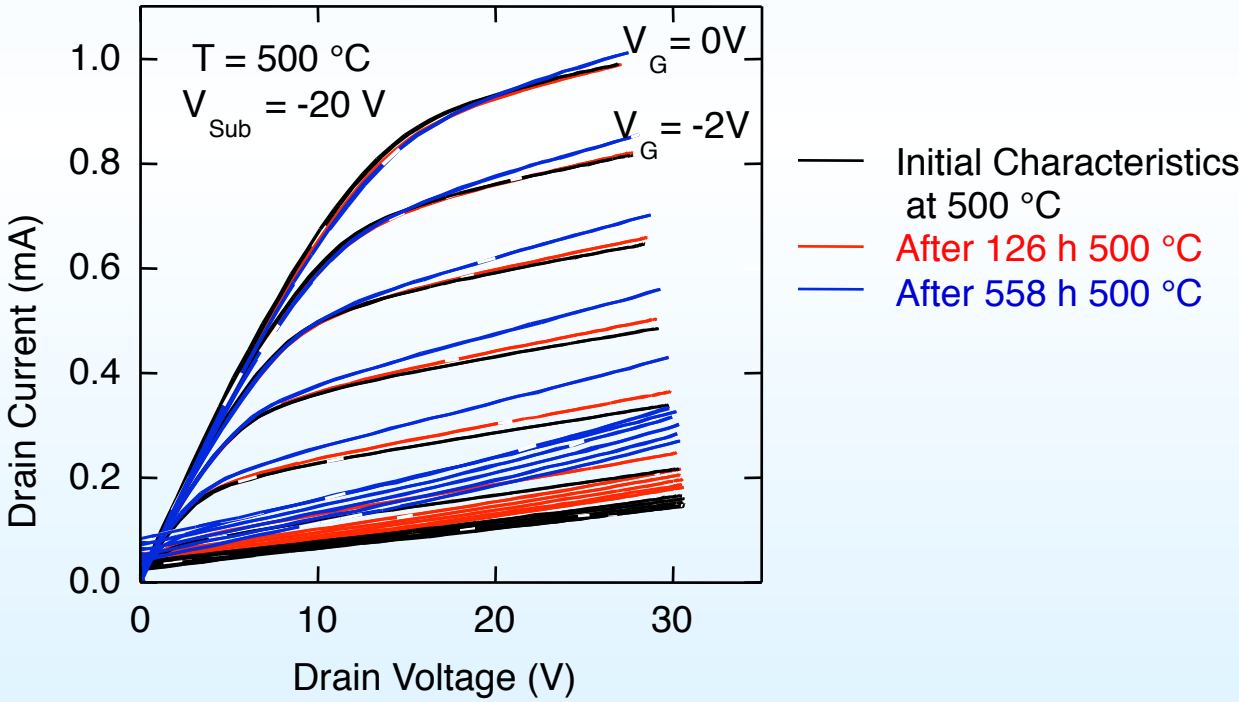
(Under Construction)



WORLD'S FIRST 500 HOUR 500 °C TRANSISTOR WITH VERY STABLE OPERATION

- 2000 hours of transistor operation achieved (some limited degradation)
- Device Operation Also Demonstrates Viability of Supporting Technologies
  - Packaging and ohmic contacts operated over 2000 hours at 500 °C without degradation.
- Strong Foundation for Improved Device Operation
  - Revised "junction gate" process should enable 2000 hours at 500 °C without transistor degradation.





WORLD'S FIRST 500 C STABLE TRANSISTOR AND ITS PERFORMANCE OVER TIME

RECENT RESULTS

6H-SiC JFET FABRICATED WITH EXCELLENT PROPERTIES

CORRECTS PREVIOUS DEFICIENCIES/TESTED AT 500C

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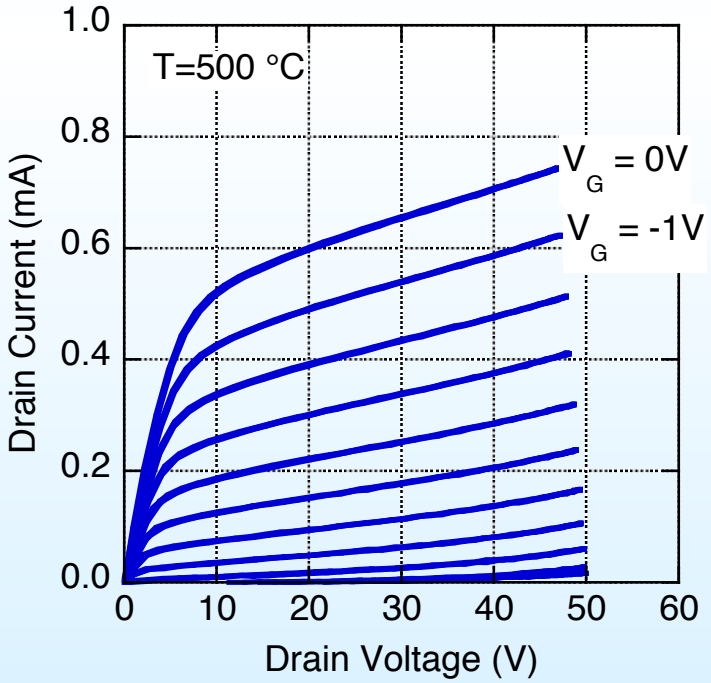
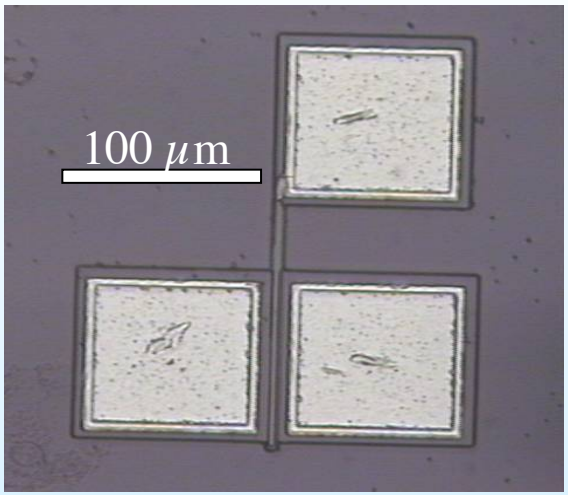
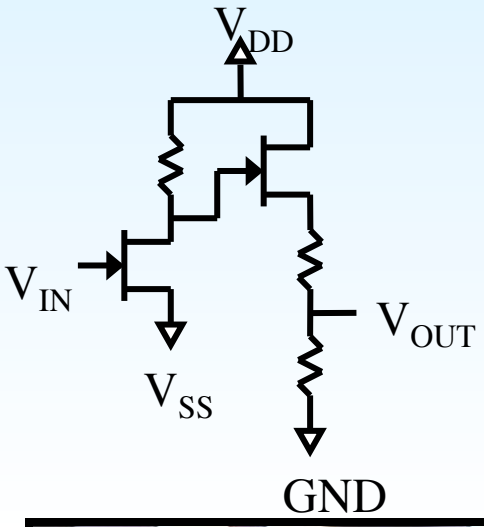
NASA Glenn 6H-SiC JFET

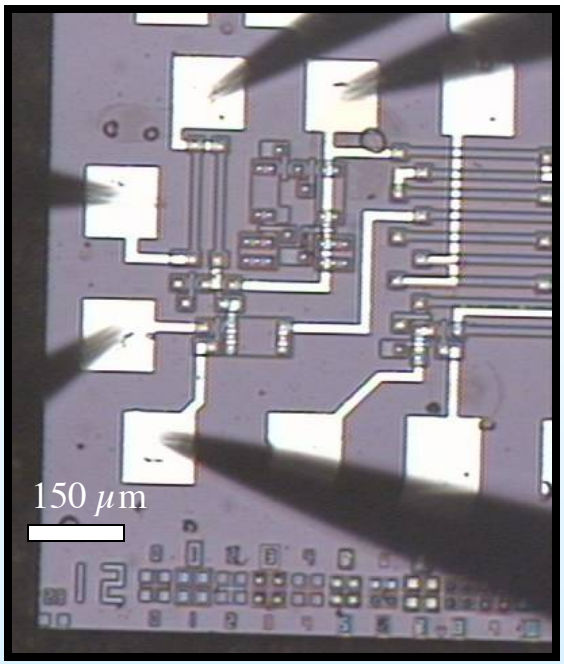




RECENT RESULTS

6H-SiC JFET Inverter (NOT Logic Gate) Tested @ 500 °C





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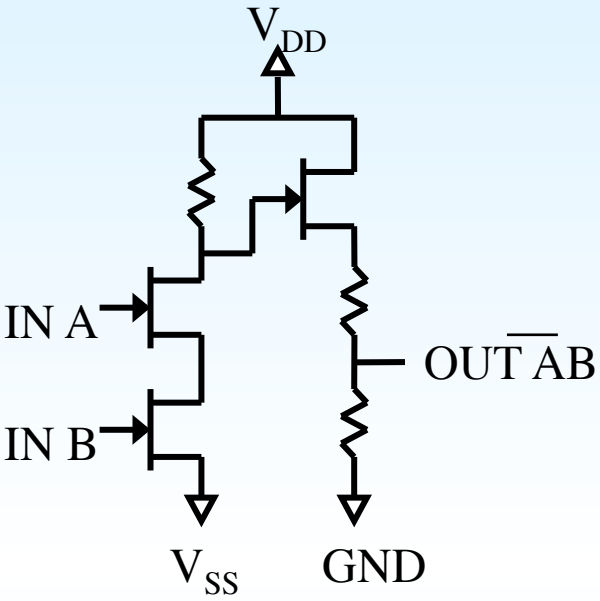
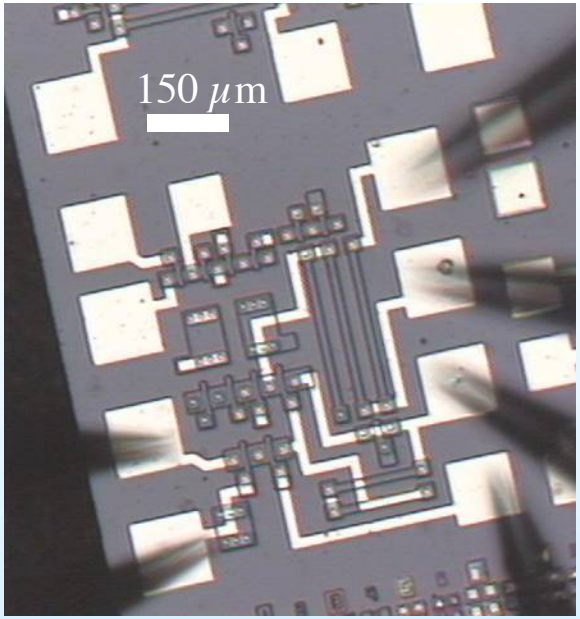
T = 500 °C

V_{DD} = 55 V, V_{SS} = 17 V, V_{SUB} = 0 V

RECENT RESULTS

6H-SiC JFET NAND Gate Tested @ 500 °C





T = 500 °C

OUT $\overline{AB}$

IN A

IN B

V_{DD} = 80 V, V_{SS} = 23 V, V_{SUB} = 0 V

SIGNIFICANCE OF RECENT ELECTRONICS RESULTS

THE BASIC COMPUTING TOOLS FOR VENUS MISSIONS HAVE BEEN FABRICATED

- FURTHER DURABILITY TESTING IS NECESSARY AT 500 C AND IS IN PROGRESS
  - SAME PACKAGING, CONTACTS ETC. THAT LASTED 2000 HOURS
  - PREVIOUS PROCESSING ERROR WHICH LIMITED LIFETIME APPEARS TO HAVE BEEN CORRECTED
- IF DURABILITY IS DEMONSTRATED, THEN THESE INTEGRATED ELECTRONICS COULD BE SCALED UP TO THE APOLLO LEVEL OF COMPUTING BUT AT 500 C
- LOGIC GATES GENERATE FLIP-FLOPS THAT CAN GENERATE STATE-MACHINES
- STATE MACHINES ENABLE:
  - CREATION OF CONTROL ELECTRONICS FOR AN "INTELLIGENT" FIXED OR MOBILE AGENT ON VENUS. DIFFERENT SENSED VARIABLES SUCH AS OBSTACLES OR TEMPERATURE CAN BE USED TO INITIATE STATE TRANSITIONS ALLOWING THE AGENT TO REACT APPROPRIATELY.
  - THE CONFIGURATION OF INTELLIGENT DATA TRANSMISSION METHODS ALLOWING FOR UNAMBIGUOUS DEMODULATION OF SIGNALS UNIQUELY ASSOCIATED WITH EACH TRANSMITTER IN A NETWORK.

High Temperature Wireless Development

OBJECTIVES:

- **HIGH TEMPERATURE WIRELESS TELEMETRY, DISTRIBUTED ELECTRONICS OVER A BROAD OPERATING RANGE**

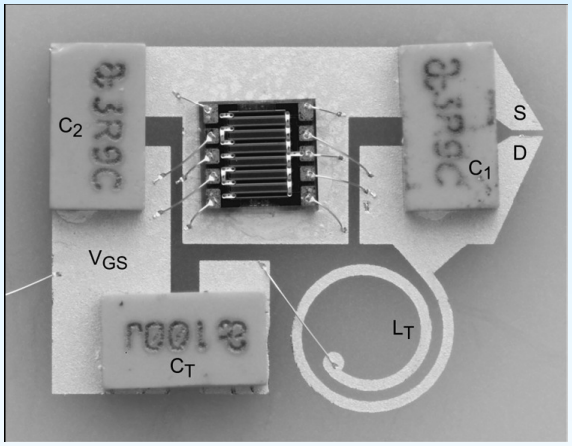
TECHNICAL CHALLENGES:

- **DEVELOPMENT OF RELIABLE HIGH TEMPERATURE TELEMETRY ELECTRONICS, POWER SOURCES, REMOTE COMMUNICATION ELECTRONICS, AND PACKAGING**

GOALS SUPPORTED:

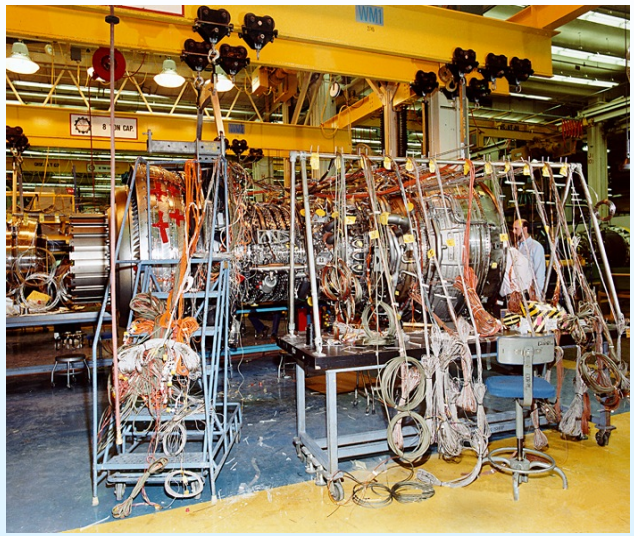
- **ENHANCE PERFORMANCE**
- **SIGNIFICANTLY REDUCE COST**

PROVIDE DATA TRANSFER IN HARSH ENVIRONMENTS IMPROVING RELIABILITY AND ENABLING NEW CAPABILITIES



Prototype Oscillator Circuit

Example: Gas Turbine Engine Development Requires Extensive Instrumentation Yielding Extensive Wiring Complexity

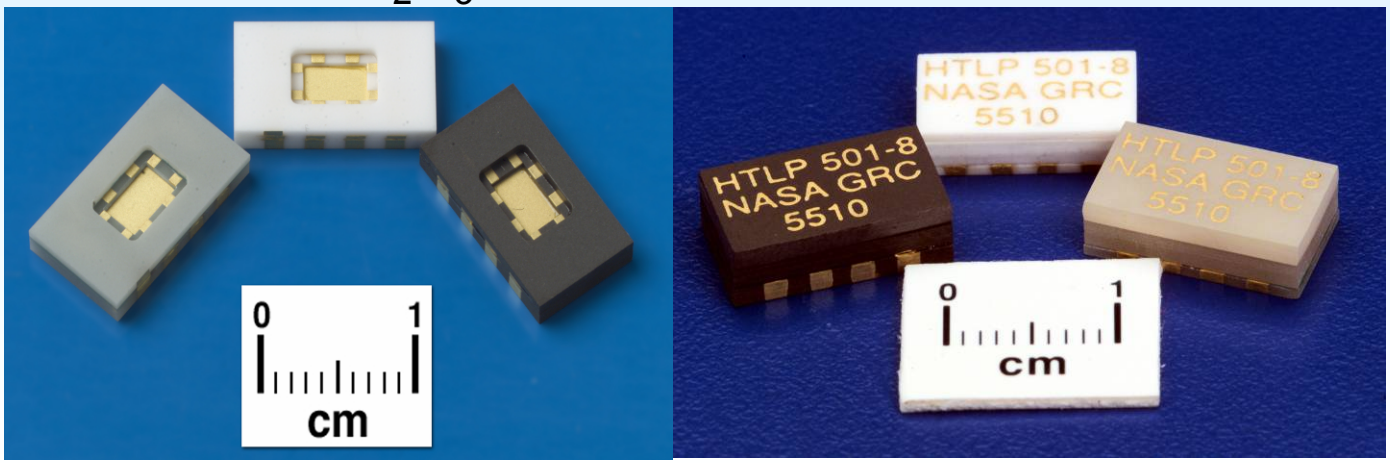


Wires from 1000 Sensors

Chip Level Packages for 500°C Application

96% Al_2O_3

AlN

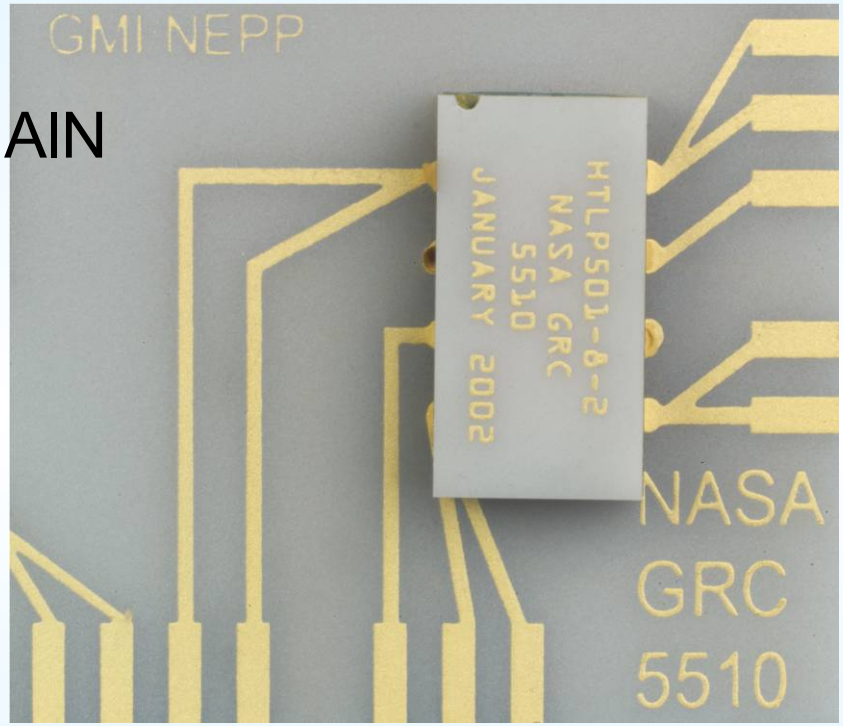


90%
Al_2O_3

- Three types of ceramic substrate and Au thick-film metallization based chip-level packages
- A compatible low resistance die-attach scheme tested for 1000hrs
- Compatible printed circuit board level interconnection system developed

Circuit Board Level Interconnection

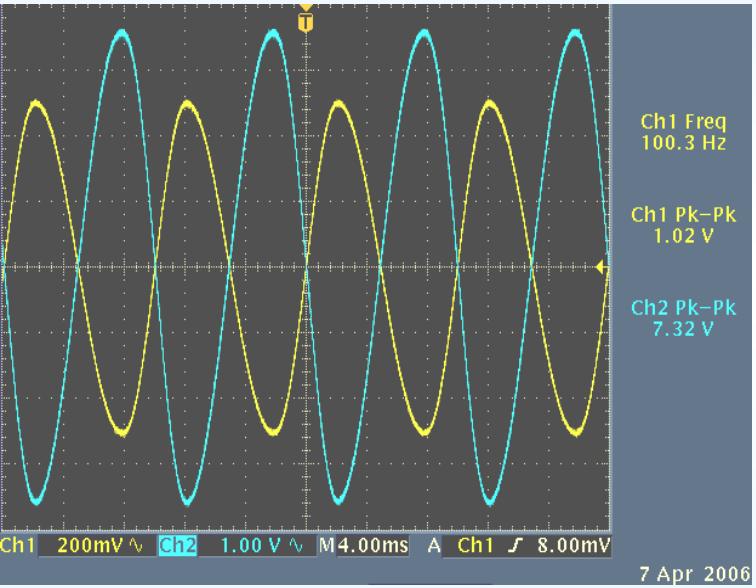
Electronic Package for High Temperature Micro-Systems

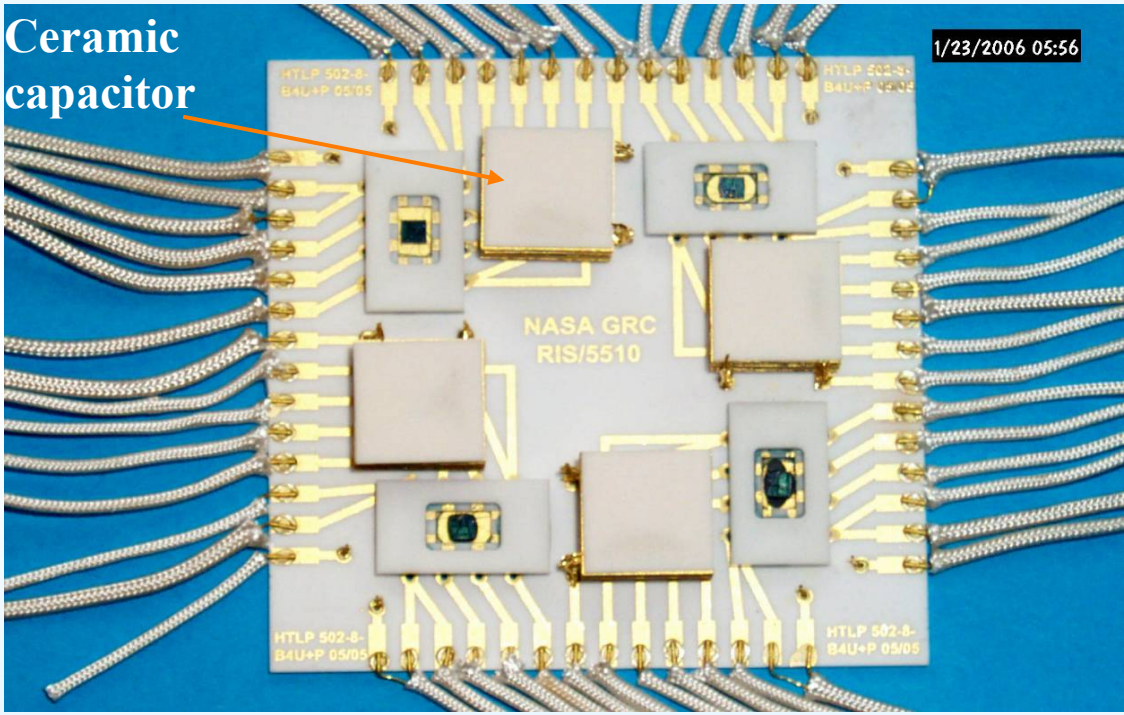


- Three types of ceramic substrate and Au thick-film metallization based PCB
- Interconnection between chip-level packages and PCB
- 500 C technology

Demonstration of 500°C AC Amplifier Based on SiC MESFET and Ceramic Packaging – Test assembly 2006

Optical Picture of the Test Assembly and Operation at 500C

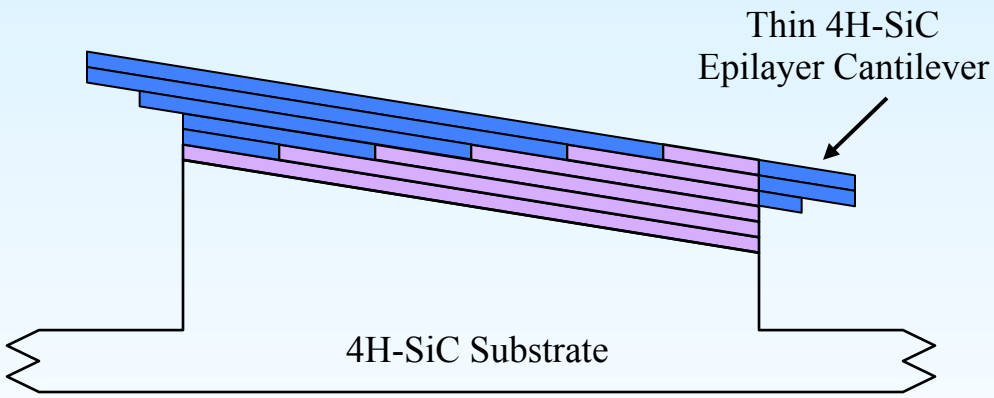




- The test assembly includes four testing circuit units
- Common - Source AC amplifier tested at 500 C for over 1100 hours

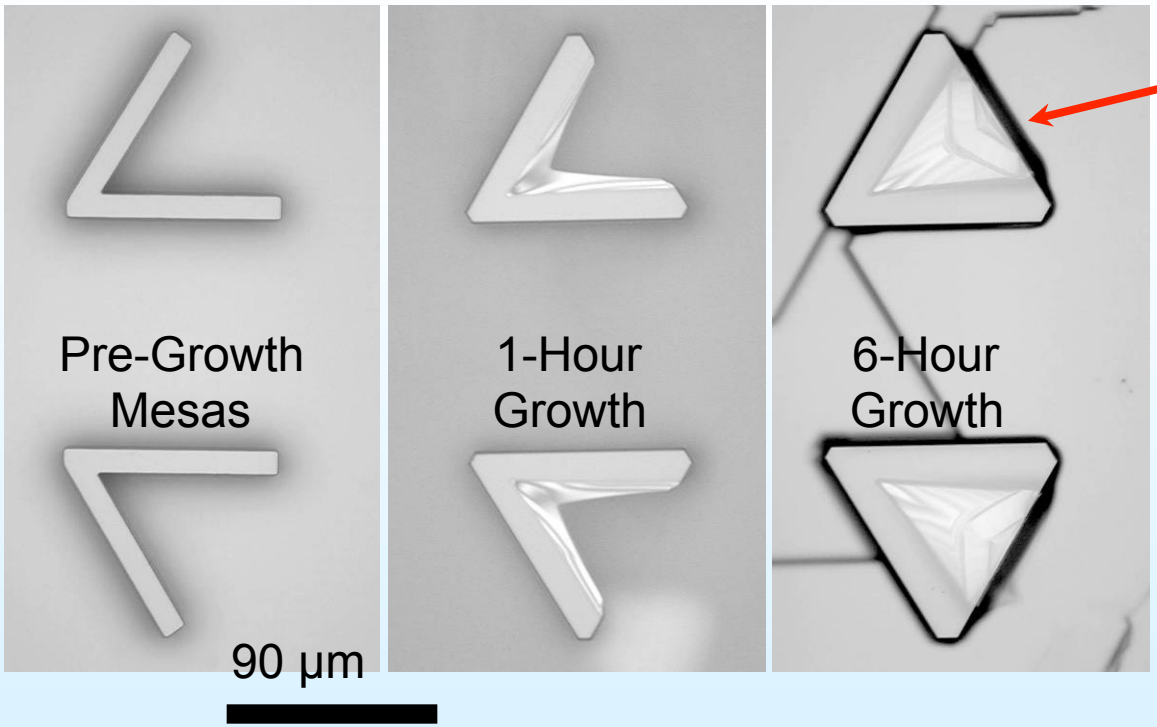
Atomically Flat SiC Mesas and Cantilevers

P. G. Neudeck et al., J. Appl. Phys. 92 p. 2391 (2002).

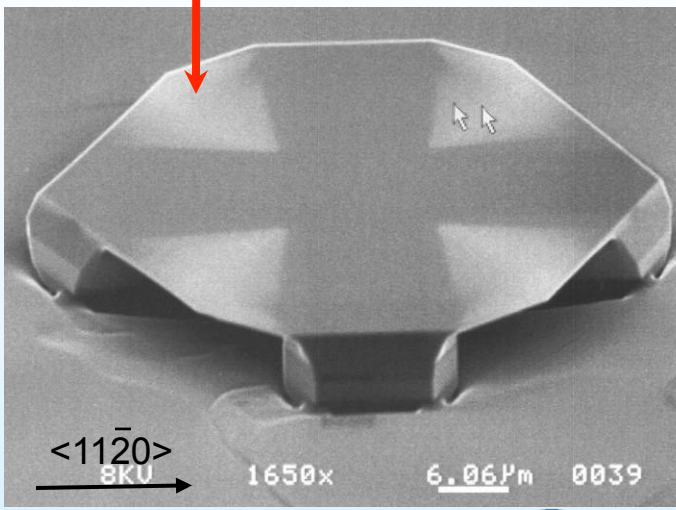


Top surface of mesa is atomically smooth completely free of steps. Surface can be enlarged by growing defect-free cantilevers.

Defect-free areas large enough for prototype devices!



Atomically Flat
"Webbed Cantilevers"

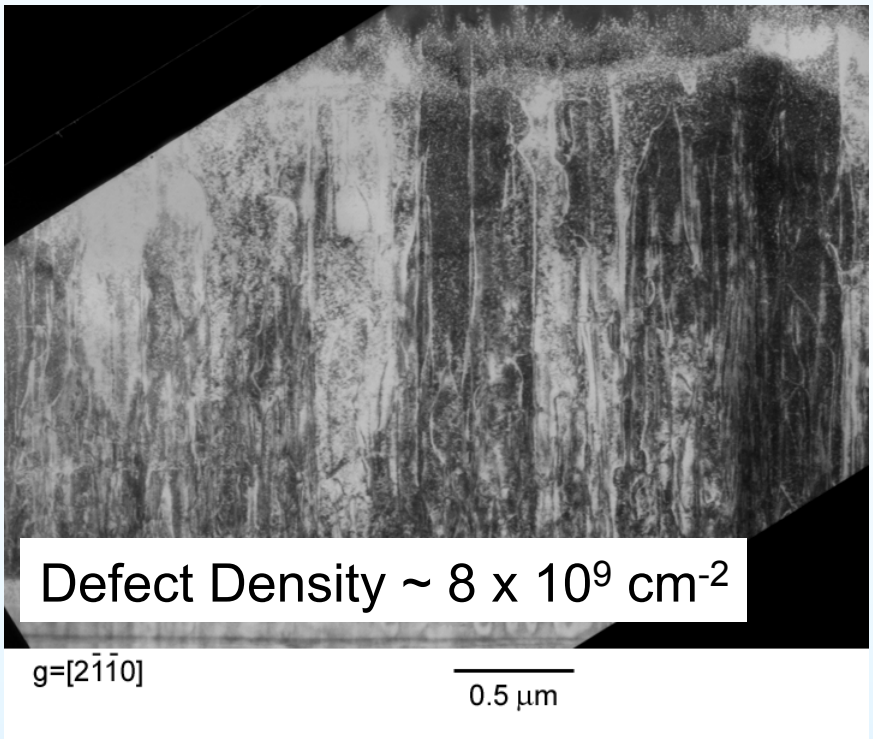


Accomplishment: Growth of Improved GaN on SiC Films

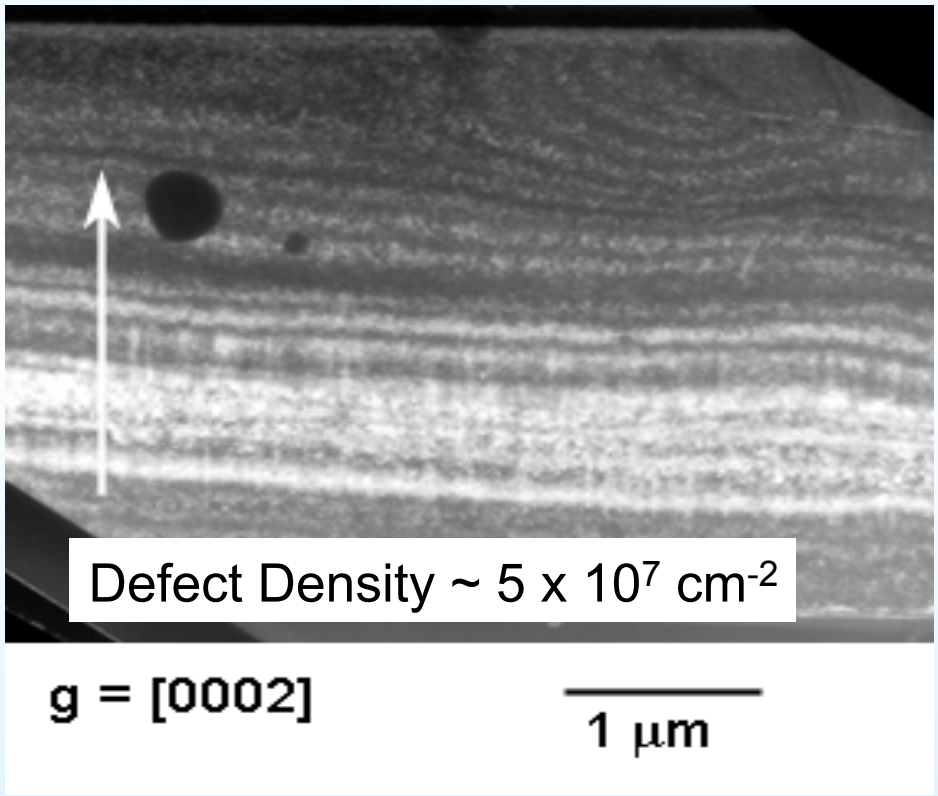
Method: Growth of GaN (by US Naval Research Laboratory) on top of Atomically Flat SiC Mesa Arrays Grown by NASA GRC.

Transmission Electron Micrographs (from NRL) Comparing GaN on SiC Films

GaN grown on top of conventional SiC with surface steps



GaN grown on top of NASA GRC SiC mesa free of surface steps



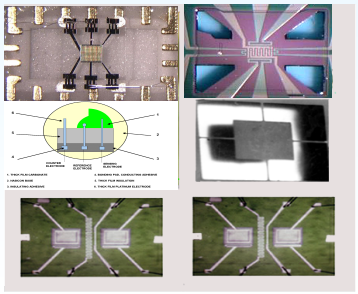
GaN Dislocation Density Reduced by 100X!

SUMMARY

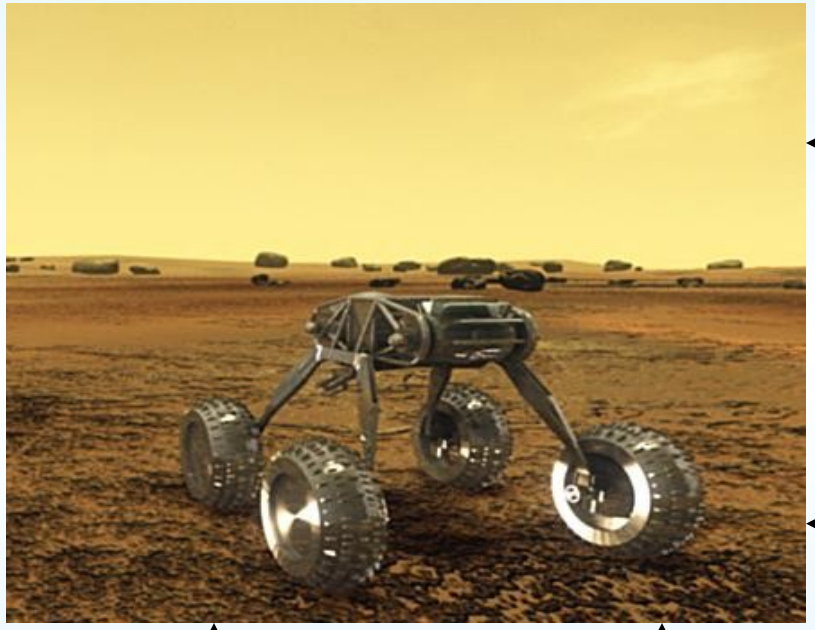
NASA GRC HAS THE TOOLS TO ENABLE NEW MISSIONS

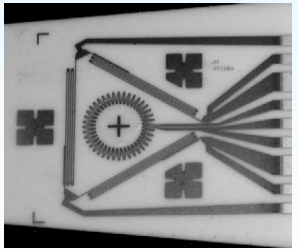
EXAMPLE POSSIBLE MISSION: Venus Integrated Weather Sensor (VIWS) System

Sensor Suite to Monitor Venus Weather Conditions including: Data Processing and Communication, Wind Flow, Seismic, Pressure/Temperature/Heat Flux, Chemical Environment

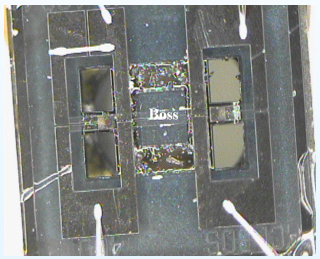


HIGH TEMPERATURE ELECTRONIC NOSE (Chemical Species)



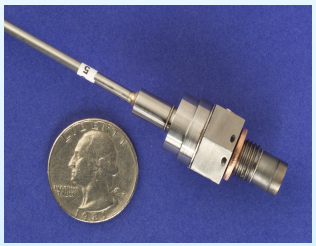


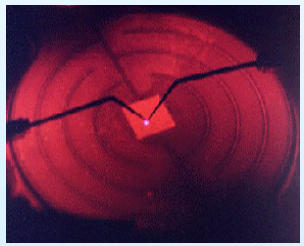
MULTIFUNCTIONAL PHYSICAL SENSOR ARRAY (Temperature, Heat Flux)



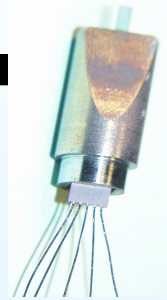
Hi-g SiC ACCELEROMETER (Seismic Activities)

PRESSURE SENSOR (Pressure)





SiC ELECTRONICS (Data Processing and Com)



HOTProbe (Wind flow, Pressure, Temperature)

BACK UP SLIDES

NASA Glenn Microsystem Development Facilities

- Significant In-House Capabilities for a Range of Micro/Nano Sensor and Electronics Development
- Capabilities Range From Semiconductor Material and Device Fabrication to Packaging and Testing
- State-Of-The-Art Facilities Leading to World Leading Technologies

SiC Chemical Vapor Deposition (CVD) Epitaxial Growth Laboratory

World's Most up-to-date Facility of Its Type

Microsystems Fabrication Clean Room

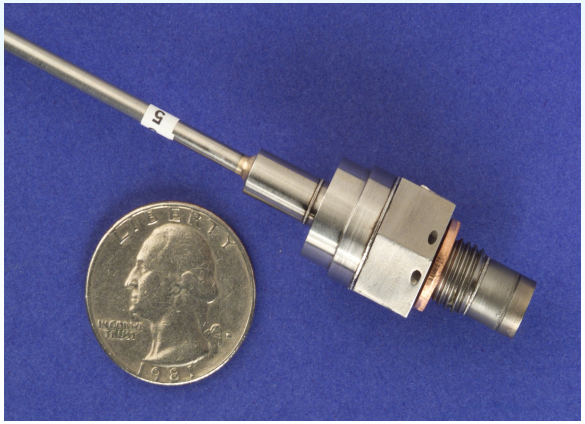
3000 Square Foot Clean Room Space for Electronic-Grade Oxides and MEMS

Microdevices Characterization Facilities

A Range of Characterization and Testing Equipment For Device Development

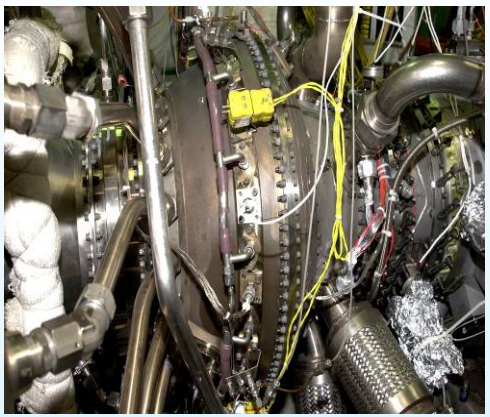
SiC-BASED PRESSURE SENSORS

- SiC HAS EXCELLENT MECHANICAL PROPERTIES FOR USE AS A HARSH ENVIRONMENT PRESSURE SENSOR (T > 500 °C, SILICON UNDERGOES PLASTIC DEFORMATION)
- FORM DIAPHRAM OF SiC AND INTEGRATE WITH ELECTRONICS
- WIDE RANGE OF APPLICATIONS
  - AERONAUTIC ENGINE APPLICATIONS
  - AUTOMOTIVE APPLICATIONS
  - MATERIAL PROCESSING
- ENGINE OPERATION DEMONSTRATED AT 500 C
- CAN BE INTEGRATED WITH FLOW VELOCITY AND TEMPERATURE FOR A VENUS HIGH TEMPERATURE WEATHER MONITORING DEVICE



500 °C SiC pressure sensor

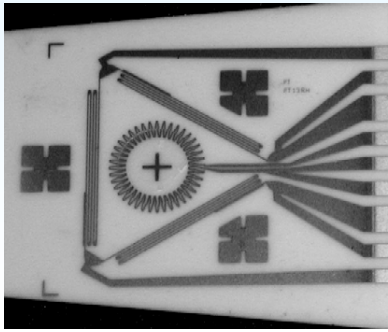
SiC High Operating Temp. Probe (HOTProbe): SiC chip to simultaneously measure flow velocity, pressure, and temperature;



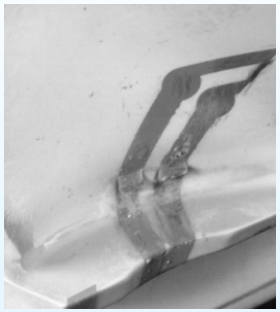
Real World Application: Pressure Sensor Installed in Engine Test

Thin Film Physical Sensors for High Temperature Applications

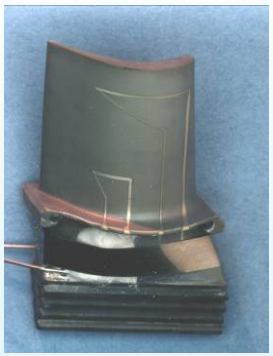
- **Advantages for temperature, strain, heat flux, flow & pressure measurement:**
  - Negligible mass & minimally intrusive (microns thick)
  - Applicable to all materials including ceramic based materials
  - Minimal structural disturbance
  - Intimate sensor to substrate contact & accurate placement
  - Multiple sensor fabrications, full-field measurement
  - High durability
  - Capable for operation to very high temperatures (> 1000°C)
- **Multifunctional smart sensors being developed**
- **Can Be Used To Measure Venus Surface Conditions as well as Monitor Vehicle Conditions**



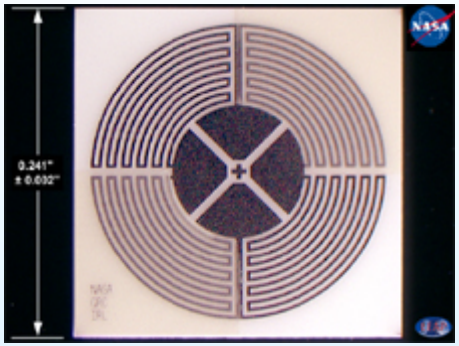
Multifunctional Sensor Array



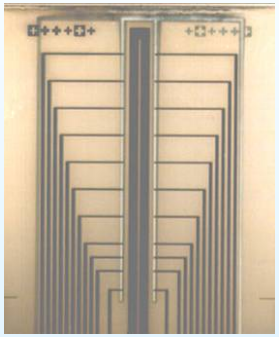
PdCr strain sensor
On Alloy to T=1000°C



Pt- Pt/Rh temperature sensor to T=1200°C



Heat Flux Sensor Array to T=1000°C



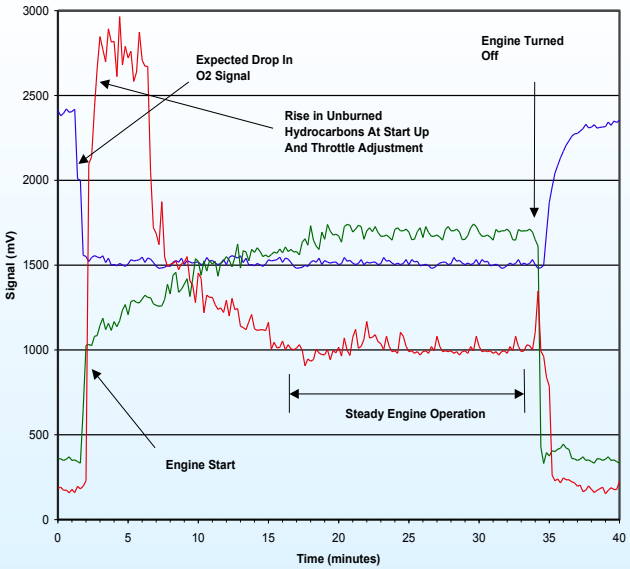
Flow sensor to T=1000°C

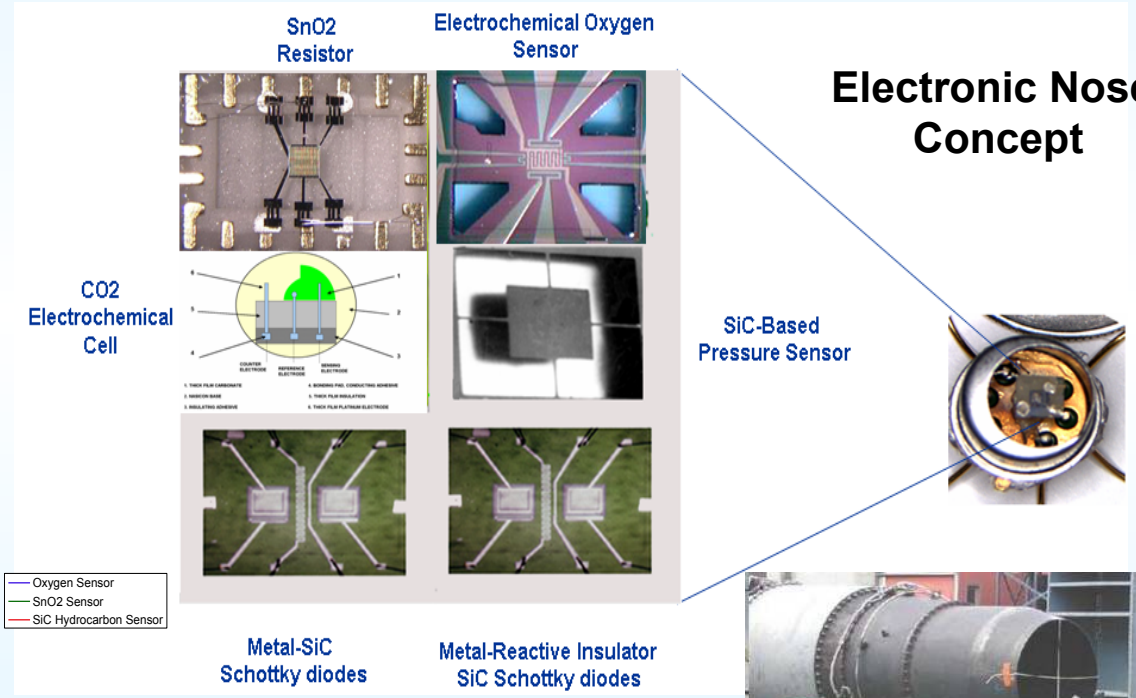
HIGH TEMPERATURE GAS SENSOR ARRAY
HIGH TEMPERATURE ELECTRONIC NOSE

THE OHIO STATE UNIVERSITY | CWRU | Makel Engineering, Inc.

- High Temperature MEMS Based Gas Sensors Designed for Selective Detection
- Multiple Chemical Species Can Be Measured/Sensors Can Be Tailored for the Application
- Multiple Species of Interest To Venus Applications Can Be Detected

Automotive Engine Sensor Testing

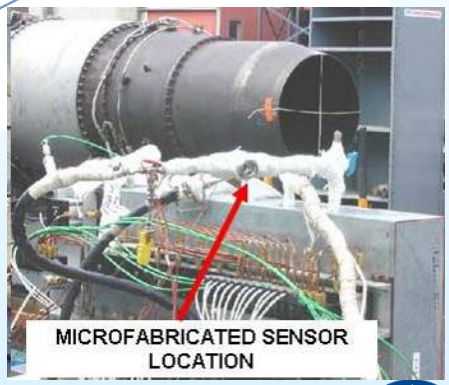




Electronic Nose Concept

SiC-Based Pressure Sensor

Jet Engine Sensor Testing



NASA